WHAT IS CLAIMED IS:

1. A transmission system for optically transmitting a frequency-division-multiplexed signal, which is obtained by frequency-division multiplexing a plurality of signals, from a transmitting end to a receiving end, comprising:

at said transmitting end,

a multiplexer for frequency-division multiplexing said plurality of signals to produce said frequency-division-multiplexed signal;

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an FM modulator for converting said frequency-division-multiplexed signal into a frequency-modulated signal through frequency modulation using said frequency-division-multiplexed signal as an original signal to output said frequency-modulated signal as an FM modulated signal; and

an optical transmitter for converting said FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in the optical frequency spectrum through optical modulation using said FM modulated signal as an original signal to send said optical-intensity-modulated signal to said receiving end, and

at said receiving end,

an optical receiver for receiving said optical-intensity-modulated signal from said optical transmitter, and converting said optical-intensity-modulated signal into an

thereof to realize high-quality signal transmission.

The present invention has the following features to attain the object above.

A first aspect of the present invention is directed to a transmission system for optically transmitting a frequency-division-multiplexed signal, which is obtained by frequency-division multiplexing a plurality of signals, from a transmitting end to a receiving end, comprising:

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at the transmitting end,

a multiplexer for frequency-division multiplexing the plurality of signals to produce the frequency-division-multiplexed signal;

an FM modulator for converting the frequency-division-multiplexed signal into a frequency-modulated signal through frequency modulation using the frequency-division-multiplexed signal as an original signal to output the frequency-modulated signal as an FM modulated signal; and

an optical transmitter for converting the FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in the optical frequency spectrum through optical modulation using the FM modulated signal as an original signal to send the optical-intensity-modulated signal to the receiving end, and

at the receiving end,

an optical receiver for receiving the optical-

intensity-modulated signal from the optical transmitter, and converting the optical-intensity-modulated signal into an electrical signal corresponding to the FM modulated signal through photodetection based on a square-law detection characteristic to output the electrical signal as a received FM modulated signal; and

an FM demodulator for demodulating the received FM modulated signal to reproduce the frequency-division-multiplexed signal.

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As described above, in the first aspect, the FM modulated signal is obtained through frequency modulation using a frequency-division-multiplexed signal as an original signal. The FM modulated signal is converted into an optical-intensity-modulated signal at the transmitting end. The optical-intensity-modulated signal has an optical frequency spectrum in which upper and lower sidebands distribute geometrically similarly to the frequency spectrum of the original signal for the optical modulation and in which an optical carrier component is suppressed. Then, the optical-intensity-modulated signal is photodetected based on a square-law detection characteristic at the receiving end. At the receiving end, the optical transmission system thus obtains an FM modulated signal, having a frequency deviation twice as large as the one of the original FM modulated signal produced at the transmitting end, as a received FM modulated signal. In this manner, the optical

Sub B2 cont.

transmission system can narrow (reduce in half) the bandwidth of the FM modulated signal at the transmitting end while securing the frequency deviation thereof large enough to acquire a sufficient FM gain in FM demodulation. As a result, it is possible to prevent the waveform of the transmitted signal from being deteriorated due to the group delay characteristic of the electrical transmission line and the chromatic-dispersion of the optical transmission line, and to realize signal transmission of good quality.

According to a second aspect, in the first aspect, the optical transmitter includes:

a light source for outputting an unmodulated light; and

an optical modulator for modulating the unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal, the optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the minimum.

As stated above, in the second aspect, the optical modulator used herein is an external optical modulator having the Mach-Zehnder interferometer structure. A modulating signal (an FM modulated signal) is applied to the optical modulator with respect to the "valley" where the output optical power is at the

minimum in the input-voltage vs. output-optical-power characteristic (which is periodic like a sine wave) of the optical modulator. The optical modulator thus produces an optical-intensity-modulated signal whose optical carrier component is suppressed. The suppression of the optical carrier component prevents the waveform from being deteriorated by the chromatic-dispersion of the optical transmission line. In addition, the optical-intensity-modulated signal has an optical frequency spectrum in which upper and lower sidebands distribute geometrically similarly to the frequency spectrum of the original signal for the optical modulation. Therefore, after the optical-intensity-modulated signal is square-law detected at the receiving end, the frequency deviation of the FM modulated signal is doubled, thereby making it possible to realize high-quality signal transmission.

According to a third aspect, in the second aspect, the transmission system further comprises,

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical modulator modulates the unmodulated light with the frequency-divided FM modulated signal to produce ~~the optical-intensity-modulated signal.~~

As described above, in the third aspect, the optical transmission system previously produces in the FM modulator an FM modulated signal having a frequency deviation larger enough to acquire a desired FM gain. The optical transmission system then converts the FM modulated signal into a frequency-divided FM modulated signal, and next converts the frequency-divided FM modulated signal into an optical-intensity-modulated signal for transmission. This reduces the phase noise in the FM modulated signal to be optically transmitted and FM demodulated. As a result, high-quality signal transmission can be realized.

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According to a fourth aspect, in the first aspect, the optical transmitter includes:

a light source for outputting an unmodulated light;

an optical branching circuit for branching the unmodulated light fed from the light source into first and second unmodulated lights;

an optical modulator for modulating the first unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal, the optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the maximum; and

an optical combining circuit for combining the optical-

intensity-modulated signal produced by the optical modulator and the second unmodulated light to cancel the optical carrier component of the optical-intensity-modulated signal with the second unmodulated light and output the optical-intensity-modulated signal whose optical carrier component is suppressed.

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As stated above, in the fourth aspect, the optical modulator used herein is an external optical modulator having the Mach-Zehnder interferometer structure. A modulating signal (an FM modulated signal) is applied to the optical modulator with respect to the "peak" where the output optical power is at the maximum in the input-voltage vs. output-optical-power characteristic (being periodic like a sine wave) of the optical modulator. The optical modulator modulates the first unmodulated light with the applied modulated signal to produce an optical-intensity-modulated signal. The optical carrier component of the optical-intensity-modulated signal is then canceled by a second unmodulated light in the optical combining circuit. The optical carrier component of the optical-intensity-modulated signal is thus suppressed, and the optical frequency spectrum thereof has upper and lower sidebands distributing geometrically similarly to the frequency spectrum of the original signal for the optical modulation. Accordingly, it is possible to prevent the waveform of the transmitted signal from being deteriorated due to the chromatic-dispersion of an optical transmission line, and to increase the frequency deviation of the FM modulated signal by

square-law detecting the above-mentioned optical-intensity-modulated signal at the receiving end, which leads to high-quality signal transmission.

Sub A2 cont

According to a fifth aspect, in the fourth aspect, the optical transmitter further includes an optical delay circuit, provided between the optical branching circuit and the optical combining circuit, for adjusting a propagation delay of at least one of the first unmodulated light, the second unmodulated light, and the optical-intensity-modulated signal produced by the optical modulator such that the second unmodulated light and the optical carrier component of the optical-intensity-modulated signal produced by the optical modulator are set in opposite phases to each other.

As described above, in the fifth aspect, the optical-intensity-modulated signal produced by the optical modulator is combined with the second unmodulated light set in an opposite phase to the optical carrier component of the optical-intensity-modulated signal. The optical carrier component of the optical-intensity-modulated signal is thus canceled by the second unmodulated light. Resultantly, it is possible to produce an optical-intensity-modulated signal whose optical carrier component is suppressed.

According to a sixth aspect, in the fourth aspect, the transmission system further comprises,

a frequency-divider provided between the FM modulator and

signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in the optical frequency spectrum through optical modulation using the FM modulated signal as an original signal to send the optical-intensity-modulated signal to the receiving end.

According to a ninth aspect, in the eighth aspect, the optical transmitter includes:

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a light source for outputting an unmodulated light; and

an optical modulator for modulating the unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal, the optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the minimum.

According to a tenth aspect, in the ninth aspect, the transmitter further comprises,

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical modulator modulates the unmodulated light with the frequency-divided FM modulated signal to produce

the optical-intensity-modulated signal.

According to an eleventh aspect, in the eighth aspect, the optical transmitter includes:

a light source for outputting an unmodulated light;

an optical branching circuit for branching the unmodulated light fed from the light source into first and second unmodulated lights;

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an optical modulator for modulating the first unmodulated light with the FM modulated signal to produce the optical-intensity-modulated signal, the optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in the input-voltage vs. output-optical-power characteristic such that the output optical power is at the maximum; and

an optical combining circuit for combining the optical-intensity-modulated signal produced by the optical modulator and the second unmodulated light to cancel the optical carrier component of the optical-intensity-modulated signal with the second unmodulated light, and output the optical-intensity-modulated signal whose optical carrier component is suppressed.

According to a twelfth aspect, in the eleventh aspect, the optical transmitter further includes an optical delay circuit, provided between the optical branching circuit and the optical combining circuit, for adjusting a propagation delay of at least

one of the first unmodulated light, the second unmodulated light, and the optical-intensity-modulated signal produced by the optical modulator such that the second unmodulated light and the optical carrier component of the optical-intensity-modulated signal produced by the optical modulator are set in opposite phases to each other.

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According to a thirteenth aspect, in the eleventh aspect, the transmitter further comprises,

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical modulator modulates the first unmodulated light with the frequency-divided FM modulated signal to produce the optical-intensity-modulated signal.

According to a fourteenth aspect, in the eighth aspect, the transmitter further comprises,

a frequency-divider provided between the FM modulator and the optical transmitter for converting the FM modulated signal outputted from the FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of the FM modulated signal, the n being an integer of not less than 1,

wherein the optical transmitter includes an optical modulator for producing the optical-intensity-modulated signal

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outputs the FM modulated signal to the electrical transmission line 102. The light source 103 outputs an unmodulated light. The optical modulator 104 receives the unmodulated light from the light source 103 and the FM modulated signal through the electrical transmission line 102, then modulates the unmodulated light with the FM modulated signal, and outputs an optical signal whose optical carrier component is suppressed. The optical modulator 104 has the Mach-Zehnder interferometer structure, for example, and is biased at the "valley" in its input-voltage vs. output-optical-power characteristic, where the output optical power is at the minimum, as shown in FIG. 3. The FM modulated signal is applied to the optical modulator 104 with respect to the voltage of an operating point 1001 which is set by the above-mentioned bias. The optical modulator 104 thus produces an optical-intensity-modulated signal (hereinafter, referred to as "optical signal") having the optical frequency spectrum in which an optical carrier component is suppressed as shown in FIG. 2B. The optical receiver 106 receives the optical signal through the optical transmission line 105, and square-law detects the signal to convert into an FM modulated signal having the frequency spectrum as shown in FIG. 2C, that is, an FM modulated signal whose carrier frequency is 2fc and whose frequency deviation is 2* ΔF. The optical receiver 106 then outputs the FM modulated signal to the FM demodulator 107. The FM demodulator 107 demodulates the FM modulated signal to reproduce the original

electrical signal corresponding to said FM modulated signal through photodetection based on a square-law detection characteristic to output said electrical signal as a received FM modulated signal; and

an FM demodulator for demodulating said received FM modulated signal to reproduce said frequency-division-multiplexed signal.

Sub A6 cont.

2. The transmission system according to claim 1, wherein said optical transmitter includes:

a light source for outputting an unmodulated light; and

an optical modulator for modulating said unmodulated light with said FM modulated signal to produce said optical-intensity-modulated signal, said optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in said input-voltage vs. output-optical-power characteristic such that the output optical power is at the minimum.

3. The transmission system according to claim 2, further comprising,

a frequency-divider provided between said FM modulator and said optical transmitter for converting said FM modulated signal outputted from said FM modulator into a frequency-divided FM

modulated signal whose frequency is $1/2^n$ the frequency of said FM modulated signal, said n being an integer of not less than 1,

wherein said optical modulator modulates said unmodulated light with said frequency-divided FM modulated signal to produce said optical-intensity-modulated signal.

Sub A6 cont.

4. The transmission system according to claim 1, wherein said optical transmitter includes:

a light source for outputting an unmodulated light;

an optical branching circuit for branching said unmodulated light fed from said light source into first and second unmodulated lights;

an optical modulator for modulating said first unmodulated light with said FM modulated signal to produce said optical-intensity-modulated signal, said optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in said input-voltage vs. output-optical-power characteristic such that the output optical power is at the maximum; and

an optical combining circuit for combining said optical-intensity-modulated signal produced by said optical modulator and said second unmodulated light to cancel the optical carrier component of said optical-intensity-modulated signal with said second unmodulated light and output said optical-

intensity-modulated signal whose optical carrier component is suppressed.

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5. The transmission system according to claim 4, wherein said optical transmitter further includes an optical delay circuit, provided between said optical branching circuit and said optical combining circuit, for adjusting a propagation delay of at least one of said first unmodulated light, said second unmodulated light, and said optical-intensity-modulated signal produced by said optical modulator such that said second unmodulated light and said optical carrier component of said optical-intensity-modulated signal produced by said optical modulator are set in opposite phases to each other.

6. The transmission system according to claim 4, further comprising,

a frequency-divider provided between said FM modulator and said optical transmitter for converting said FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of said FM modulated signal, said n being an integer of not less than 1,

wherein said optical modulator modulates said first unmodulated light with said frequency-divided FM modulated signal to produce said optical-intensity-modulated signal.

7. The transmission system according to claim 1, further comprising,

a frequency-divider provided between said FM modulator and said optical transmitter for converting said FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of said FM modulated signal, said n being an integer of not less than 1,

wherein said optical transmitter includes an optical modulator for producing said optical-intensity-modulated signal through said optical modulation using said frequency-divided FM modulated signal as an original signal.

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8. A transmitter for use in a transmission system for optically transmitting a frequency-division-multiplexed signal, which is obtained by frequency-division-multiplexing a plurality of signals, from a transmitting end to a receiving end, comprising:

a multiplexer for frequency-division multiplexing said plurality of signals to produce said frequency-division-multiplexed signal;

an FM modulator for converting said frequency-division-multiplexed signal into a frequency-modulated signal through frequency modulation using said frequency-division-multiplexed signal as an original signal to output said frequency-modulated signal as an FM modulated signal; and

an optical transmitter for converting said FM modulated signal into an optical-intensity-modulated signal whose optical carrier component is suppressed in the optical frequency spectrum through optical modulation using said FM modulated signal as an original signal to send said optical-intensity-modulated signal to said receiving end.

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9. The transmitter according to claim 8, wherein said optical transmitter includes:

a light source for outputting an unmodulated light; and

an optical modulator for modulating said unmodulated light with said FM modulated signal to produce said optical-intensity-modulated signal, said optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in said input-voltage vs. output-optical-power characteristic such that the output optical power is at the minimum.

10. The transmitter according to claim 9, further comprising,

a frequency-divider provided between said FM modulator and said optical transmitter for converting said FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of said

FM modulated signal, said n being an integer of not less than 1,

wherein said optical modulator modulates said unmodulated light with said frequency-divided FM modulated signal to produce said optical-intensity-modulated signal.

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11. The transmitter according to claim 8, wherein said optical transmitter includes:

a light source for outputting an unmodulated light;

an optical branching circuit for branching said unmodulated light fed from said light source into first and second unmodulated lights;

an optical modulator for modulating said first unmodulated light with said FM modulated signal to produce said optical-intensity-modulated signal, said optical modulator having the Mach-Zehnder interferometer structure with a predetermined input-voltage vs. output-optical-power characteristic, and being biased in said input-voltage vs. output-optical-power characteristic such that the output optical power is at the maximum; and

an optical combining circuit for combining said optical-intensity-modulated signal produced by said optical modulator and said second unmodulated light to cancel the optical carrier component of said optical-intensity-modulated signal with said second unmodulated light, and output said optical-intensity-modulated signal whose optical carrier component is

suppressed.

12. The transmitter according to claim 11, wherein said optical transmitter further includes an optical delay circuit, provided between said optical branching circuit and said optical combining circuit, for adjusting a propagation delay of at least one of said first unmodulated light, said second unmodulated light, and said optical-intensity-modulated signal produced by said optical modulator such that said second unmodulated light and said optical carrier component of said optical-intensity-modulated signal produced by said optical modulator are set in opposite phases to each other.

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13. The transmitter according to claim 11, further comprising,

a frequency-divider provided between said FM modulator and said optical transmitter for converting said FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of said FM modulated signal, said n being an integer of not less than 1,

wherein said optical modulator modulates said first unmodulated light with said frequency-divided FM modulated signal to produce said optical-intensity-modulated signal.

14. The transmitter according to claim 8, further

comprising,

a frequency-divider provided between said FM modulator and said optical transmitter for converting said FM modulated signal outputted from said FM modulator into a frequency-divided FM modulated signal whose frequency is $1/2^n$ the frequency of said FM modulated signal, said n being an integer of not less than 1,

wherein said optical transmitter includes an optical modulator for producing said optical-intensity-modulated signal through said optical modulation using said frequency-divided FM modulated signal as an original signal.

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